A STATIC SCALE-MODEL SIMULATOR FOR THE STUDY OF VISIBILITY AND HIGHWAY LIGHTING

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•FIELD studies of visibility and highway lighting have proved difficult and expensive. Accordingly, we have developed a scale-model simulator to use as an adjunct to field measurements. The intention is that the simulator be used first in a careful series of studies, followed by spot-checking in the field. Tests conducted both in the simulator and in the field will involve static viewing at the outset. Subsequently, it may be possible to extend the measurement techniques for use under dynamic conditions.

GENERAL DESIGN FEATURES

The model scale was set at $^1/_{15}$ so that we could simulate a 600-ft section of roadway within the largest room available to us. The roadway is shown in Figure 1. It is 120 scale ft in width, with four 12-ft lanes on either side of a 24-ft median strip. The surfaces are portland cement concrete on the right and bituminous concrete on the left. The optical properties of these surfaces were made to simulate the properties of actual sections of new roadway surfaces on the basis of goniophotometric determinations with an instrument developed by a former colleague, A. J. Birkhoff. There is a median divider built to simulate dividers in common use.

Luminaires are mounted above the roadway on "pendulum poles" of varying length to simulate different mounting heights. There is a mechanical coupling and an electrical outlet every 20 ft in each of four strings running the entire length of the roadway. The two outer strings are near the outer edges of the roadway. The two inner strings are near the edges of the median strip.

There are locations for luminaires beyond the roadway surface at each end. In all there are 164 locations for luminaires and an equal number of electrical outlets. Each outlet is supplied with voltage-stabilized 100 Vac controlled by an individual Variac. A voltage switching control board makes it possible to monitor the voltage being supplied to each output in turn, reading the value on a nixie tube. This arrangement makes it very convenient for the operator to adjust the voltage supply to each luminaire to a standard value.

There is a separate light projector on each side of the roadway that illuminates pieces of roadway surface mounted on the wall at the far end of the simulator to provide a realistic visual continuation of the highway in perspective. By using separate Variac controls, luminance of these sections of surface is adjusted to match the average luminance of the roadway provided by a given layout of luminaires.

The patterns of horizontal and vertical illumination produced under test conditions are measured with a mobile illumination photometer. The sensor is a barrier-layer photocell whose angular response follows the cosine law. The signal from the photocell is broadcast by an FM transmitter mounted on the photometer carriage and received at the observation station at the rear of the simulator. The signal is used to drive the y axis of an x-y plotter and also is used to generate an auditory tonal signal whose frequency corresponds to signal strength.

The photocell carriage is moved back and forth along the roadway just above the surface. The carriage is driven by a chain drive mounted in the median strip divider. An

Sponsored by Committee on Visibility and presented at the 50th Annual Meeting.

arm extends out from the median strip across the roadway to a protective strip at each edge of the roadway, and the photocell is mounted on this arm at any desired distance from very close to the median divider to near the outer edge of the roadway on either side. The photocell carriage is driven by a braked variable-speed drive that makes it possible to stop it at any point within less than 1 scale ft.

There is a continuous circuit board of reed switches running the entire length of the roadway within the median strip. As the carriage moves along the roadway, its precise position is indicated by the circuit board assembly to within 1 scale ft. The signal from the circuit board is used both to drive the x axis of the x-y plotter and to operate a nixie tube readout device calibrated in scale feet.

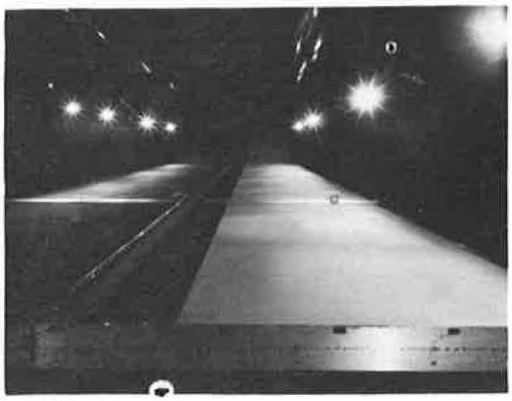

Figure 1. View down the roadway from the observation station showing luminaires and portland cement concrete and bituminous concrete sections on either side of median strip.

The illumination photometer may be used to record continuous illumination profiles running longitudinally along the roadway at various transverse locations.

There is an instrument carriage at the observation end of the simulator. An operator views the roadway at the simulated angle appropriate for the driver of an automotive vehicle. One device used by the operator is a special contrast-reducing visibility meter known as the Blackwell VTE Model 3 (1). This device gives the operator a telescopic view of objects on the roadway. The device produces a luminance veil that is set equal to the luminance surrounding the object, using the flicker photometer mode of the instrument. A contrast control is then operated that gradually reduces the magnitude of focused light reaching the eye of the operator from the object and its background and at the same time increases the magnitude of light veil, with the restriction that the total of focused light and light veil is maintained at a nearly constant value. As the contrast is reduced, the object is brought to the visibility threshold. The extent to which contrast reduction is required provides a quantitative measure of the initial visibility of the object.

The operator also has available a luminance photometer (the Spectra Pritchard photometer, manufactured by the Photo Research Corporation, Burbank, California) with variable apertures that is capable of sampling the luminance of an area no larger than 1 scale foot on the object or its background. There is also an optical analog device serving as an attachment to the photometer that integrates all components of disability glare in the environment, thus simulating the behavior of the human eye.

The instrument carriage has a precision motor-driven mounting table with two positions, as shown in Figure 2. In the first position, the visibility meter is pointed precisely at an object of interest, in this case a mannequin. In the second, the photometer is pointed precisely at the same object.

THE SCALE-MODEL LUMINAIRES

Great care was taken to design and fabricate luminaires to represent the common types in general use. The design finally adopted is shown in Figure 3. Each luminaire is based on four 75-watt quartz-iodine lamps, with the filaments precision-aligned at angles off vertical. There are four Alzac plane mirrors to produce multiple images of each filament. All these components are precision-mounted in a rectangular aluminum case with a controlled bottom slot and adjustable end slots. There is also a stainless steel grid that consists of three pieces of stainless steel mesh; one piece is coarse and serves as a supporting element, whereas the other two are very fine and overlap at the center. The entire grid serves as a variable density optical filter capable of withstanding the very high temperatures created by the luminaire units.

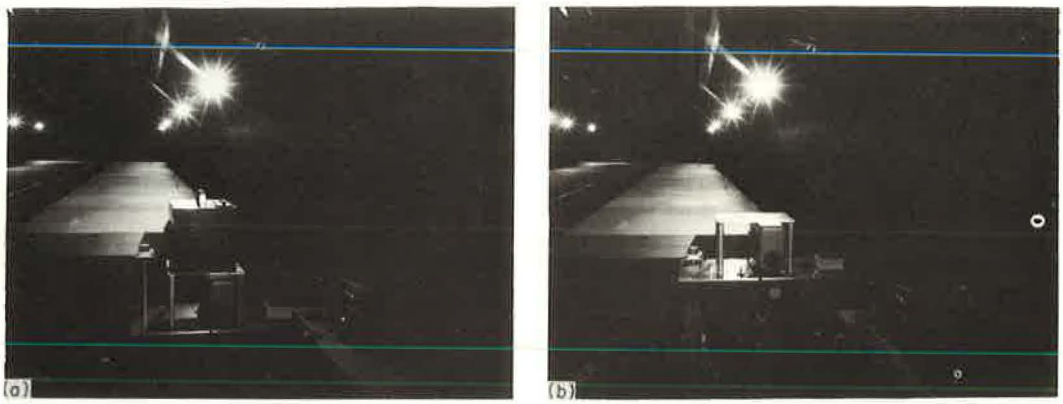

Figure 2. View of the instrument carriage with (a) visibility meter pointed at mannequin placed on roadway under luminaires and (b) luminance photometer pointed at mannequin in precise alignment with view seen through visibility meter telescope.

The luminaires are mounted on precision-tilted caps mounted in aluminum tubes used in the pendulum mounts. When a type III luminaire is required a 20-deg tilt cap is used, whereas a 15-deg tilt cap is used to simulate a type II luminaire. The end flaps are used to cut off the candlepower distribution at very high angles to represent the change from a type MSC to a type MC luminaire.

Design of the luminaires proceeded by elaborate trial and error. Although both illumination and candlepower measurements were used in this process, the illumination measurements were found to be more helpful in guiding design, and primary reliance was placed on these measurements.

After prototyping, a final design was turned over to the Institute instrument maker, who fabricated 56 luminaires to the design. Careful measurements were made on a random sample selected from among the 56. Spot-checking suggests that the individual luminaires are very similar to the selected sample.

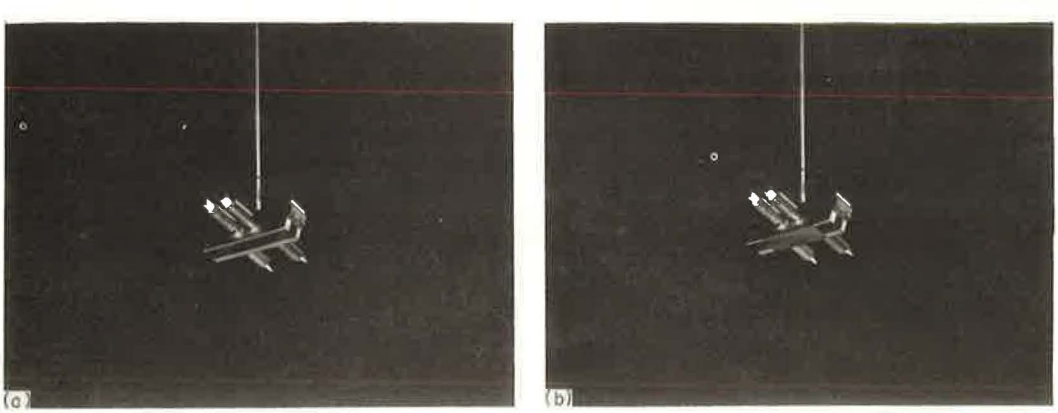

Figure 3. Close-up view of the scale-model luminaire with (a) stainless steel grid removed and (b) stainless steel grid in place.

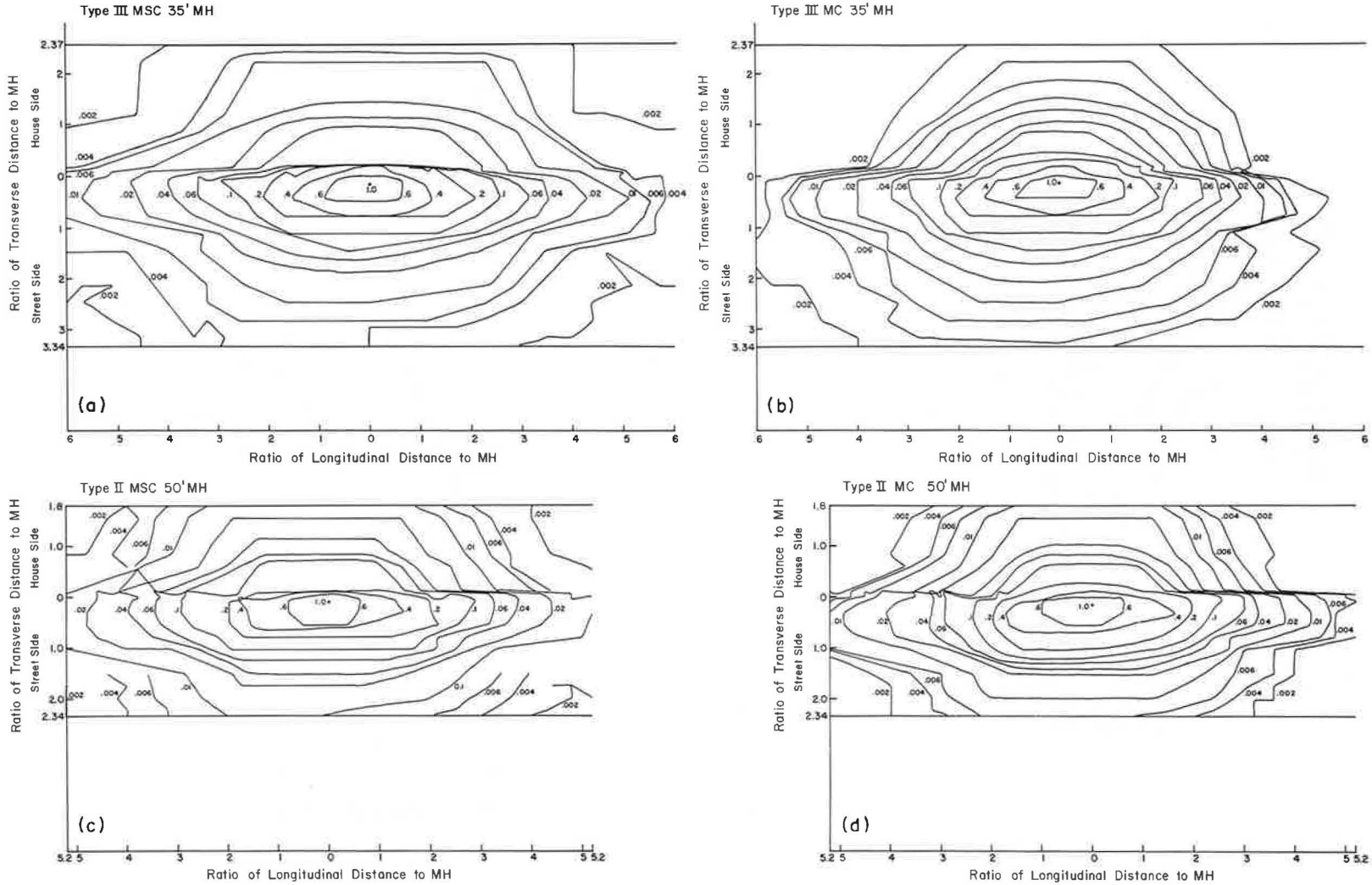

Figure 4. Iso-illuminance contours (expressed proportional to the maximum as unity) for the scale-model luminaire (a) in mode type III MSC; (b) in mode type III MC; (c) in mode type II MSC; and (d) in mode type II MC.

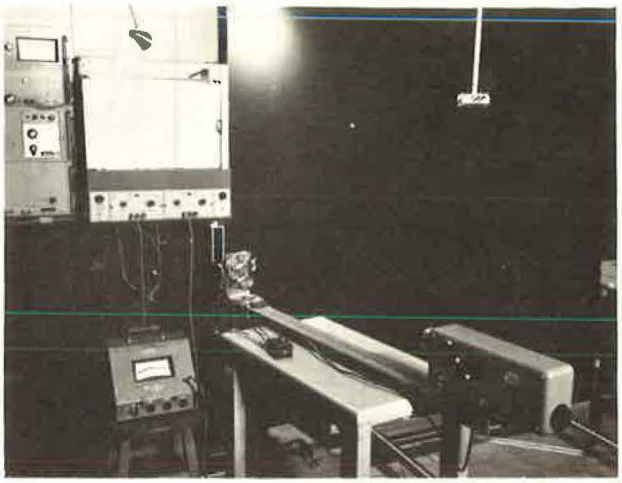

Figure 5. Setup for measuring luminaire candlepower using automatic transit and x-y plotter.

In making careful illumination measurements on the sample luminaire, precision was increased by stringing a wire from the photocell to an amp-volt converter and then to a digital voltmeter operating on a 1-volt range. The mobile photometer was stopped at discrete points every 20 scale ft along the roadway for each of 13 transverse locations. Graphs of the longitudinal illuminance profiles along each of the 13 transverse locations were used to determine the iso-illuminance contours shown in Figure 4 for the four types of luminaires: type III MSC, type III MC, type II MSC, and type II MC. We regard these data as adequate evidence of the success of our simulation effort.

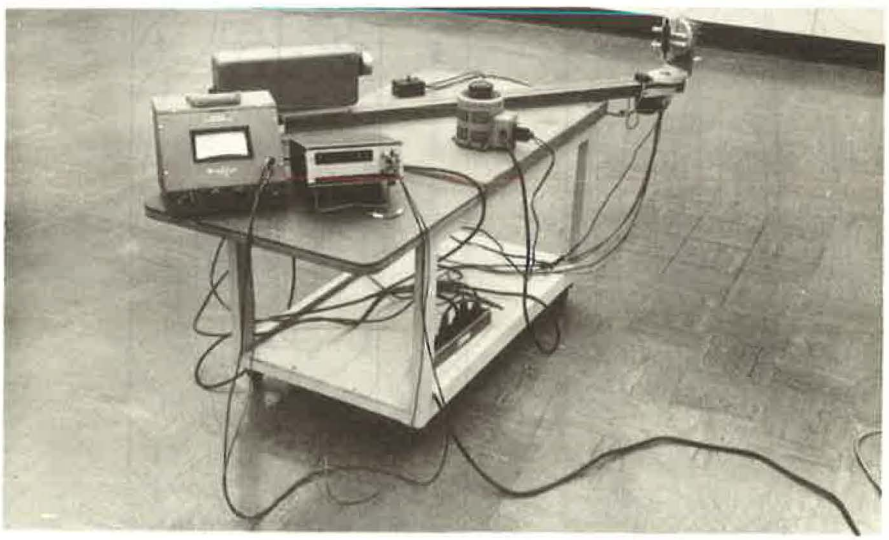

Figure 6. Setup for measuring luminaire candlepower using manual transit and digital voltmeter.

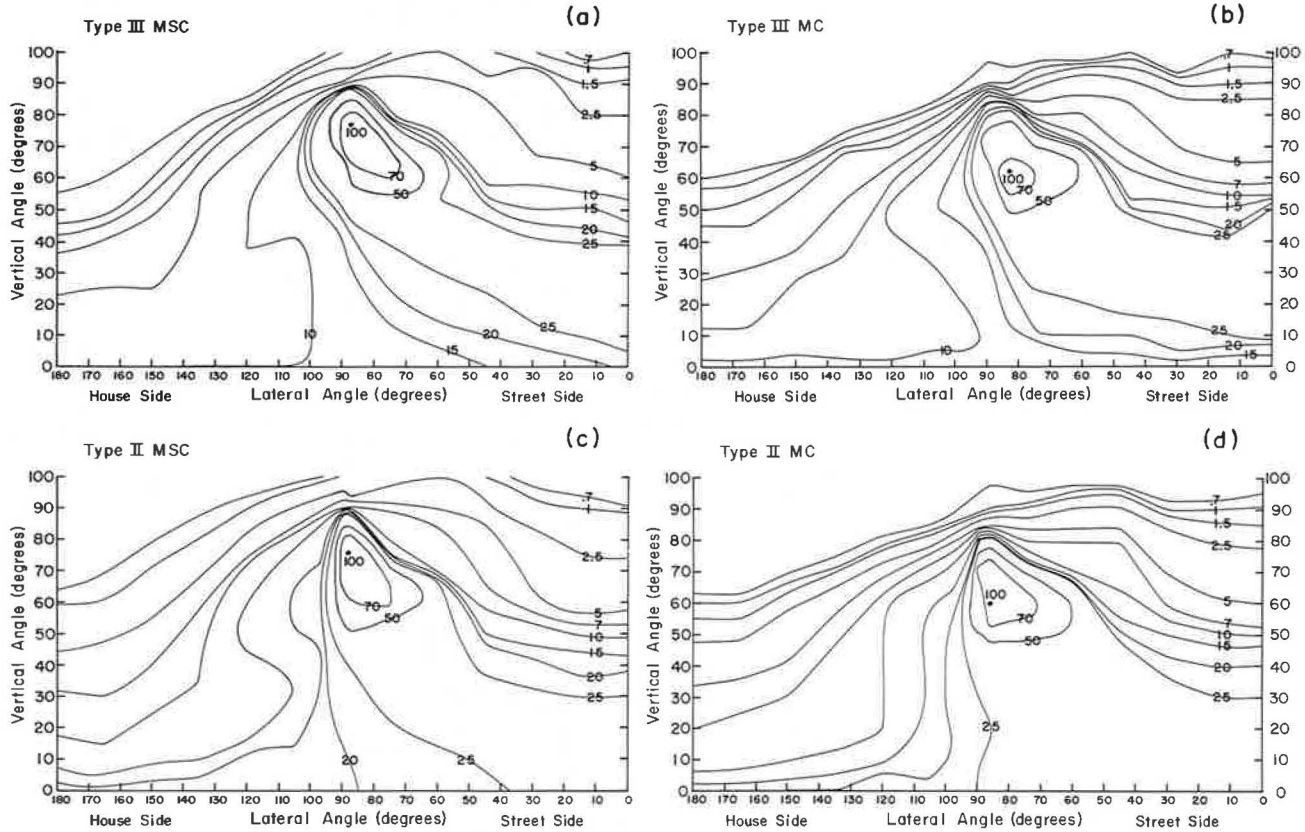

Figure 7. Iso-candlepower contours (expressed proportional to the maximum as 100) for the scale-model luminaire (a) in mode type III MSC; (b) in mode type III MC; (c) in mode type II MSC; and (d) in mode type II MC.

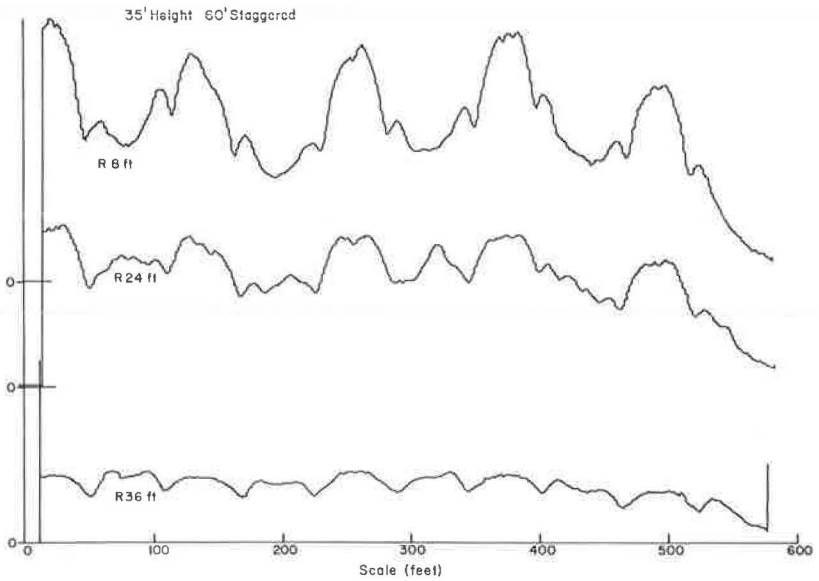

Figure 8. Data record of the horizontal illuminance at three transverse locations with luminaires at 35-ft mounting height and 60-ft staggered spacing.

However, for the record, we have also measured candlepower profiles in the manner usually used by the manufacturers of commercial roadway luminaires. This may be done quickly with somewhat reduced precision with the setup shown in Figure 5. The luminaire is slowly rotated through the vertical angle by a motor-driven transit, with the candlepower measured with the luminance photometer operating in the flux mode. The output from the photometer is fed to the y axis of the x-y plotter while the transit location is read out on the x axis of the x-y plotter. This setup was employed during the trial-and-error design period. Our careful measurements were made with the setup shown in Figure 6. Here the rotation is achieved manually, and the output from the photometer is fed to the digital voltmeter.

Candlepower readings were made by recording values at fixed vertical angles at each of 20 lateral angles. Contours of fixed candlepower were read from graphs of the raw data with the results shown in Figure 7. Again, these data support the adequacy of our simulation.

Figure 8 is a data record taken with luminaires mounted as shown in Figure 1, with a 35-ft mounting height and with 60-ft staggered spacing. Transverse locations were 8, 24, and 36 scale ft to the left of the right-hand edge of the roadway. The luminaires had an overhang of 3 ft in from the outside on each side.

CONCLUSIONS

We have completed development of our scale-model roadway simulator and are now beginning a program of measurements to ascertain the visibility of objects such as mannequins, vehicles, and roadway markings under different layouts of our four types of roadway luminaires. The simulator is quite convenient and appears to represent a valuable tool in future studies of visibility and illumination variables on the roadway.

Authors' addendum: Further study has suggested that our simulation of the candlepower distributions of the four luminaires departs from current practice by having too long but too narrow a pattern of maximal illumination on the roadway and by failing to produce as good cut-off at high angles.

ACKNOWLEDGMENTS

Research on the project reported here was supported in part by the Ohio Department of Highways and the Federal Highway Administration and in part by the Illuminating Engineering Research Institute. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Ohio Department of Highways or the Federal Highway Administration.

REFERENCE

1. Blackwell, H. R. Development of Procedures and Instruments for Visual Task Evaluation. Illuminating Engineering, Vol. 65, No. 4, pp. 267-291, 1970.